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# Laser plasma simulations by Arbitrary Lagrangian Eulerian method

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**Abstract.** Arbitrary Lagrangian Eulerian (ALE) method is able to avoid severe computational mesh distortion of Lagrangian methods by smoothing the mesh and remapping conserved quantities to the new mesh. High power laser interactions with disc flyer targets are simulated by the developed ALE code. Pure Lagrangian method is unable to treat these problems due to severe grid distortion, while ALE method produces acceptable results.

## 1. INTRODUCTION

Laser plasma is usually modeled as a compressible fluid by Euler equations in Lagrangian coordinates. The Lagrangian approach with a computational mesh moving with the fluid is much better suited for compression and expansion regimes with moving boundaries, which appear often in laser plasma, than the Eulerian approach on the static mesh. Lagrangian hydrodynamical system with heat conductivity and laser absorption is given by

$$\frac{1}{\rho}\frac{d\rho}{dt} = -\nabla\cdot\vec{v}, \qquad \rho\frac{d\vec{v}}{dt} = -\nabla\cdot p, \qquad \rho\frac{de}{dt} = -p\,\nabla\cdot\vec{v} + \nabla\cdot(\kappa\nabla T) - \nabla\cdot\vec{I}, \tag{1}$$

where $t$ is time, $\rho$ mass density, $\vec{v}$ speed, $p$ pressure, $e$ internal energy, $T$ temperature, $\kappa$ heat conductivity and $\vec{I}$ laser intensity. Many simulated problems in laser plasma involve however complex flows with e.g. shear waves or physical instabilities which deform Lagrangian mesh moved by the flow so much that it becomes invalid (with non-convex or even inverted cells) and Lagrangian computation cannot continue. Arbitrary Lagrangian Eulerian (ALE) method [1] offers a possibility to avoid distortions of moving Lagrangian meshes. After several time steps of Lagrangian simulation or when the mesh becomes distorted, the deformed mesh is smoothed out by rezoning, the conservative quantities are conservatively remapped from the deformed mesh to the smother one and Lagrangian computation can continue.

## 2. NUMERICAL METHOD

The mixed system of hyperbolic-parabolic partial differential equations (1) has to be solved numerically and is treated by splitting into its hyperbolic and parabolic parts. The parabolic heat equation is solved numerically by mimetic, support operators method. For numerical treatment of hyperbolic part of (1) the Arbitrary Lagrangian-Eulerian (ALE) method [1] is used. It consists of several Lagrangian computational steps, followed by grid smoothing and remapping (Eulerian part) of conservative quantities from the old grid to the new smoother one, after which it returns back to Lagrangian steps. For Lagrangian method we use compatible hydrodynamic algorithm [2] with subzonal pressures preventing hourglass type grid motion. For mesh smoothing we employ simple Winslow rezoning method. Remapping in performed by efficient swept area integration [3]. The hydrodynamics uses the quotidian equation of state (QEOS) [4] which is valid in a broad range of plasma conditions. For heat conductivity the classical Spitzer-Harm model is employed. The laser radiation is modeled by the simplest approximation. The radiation penetrates till the critical density and is absorbed at the critical surface.

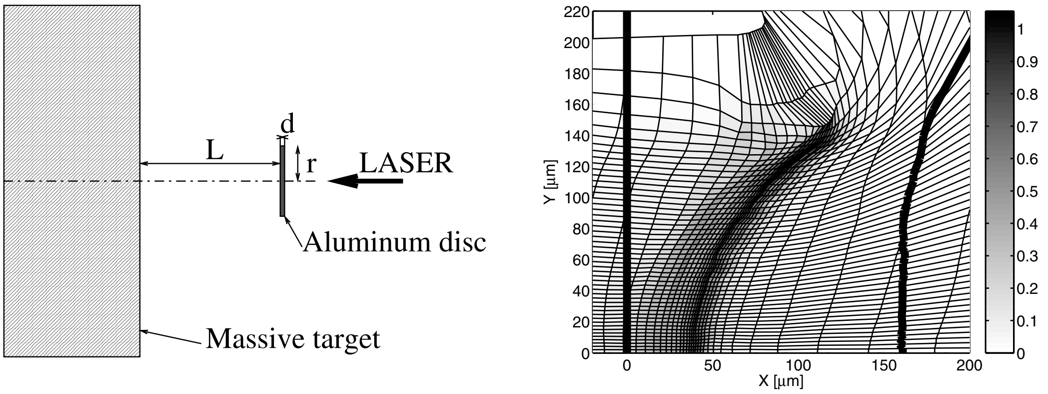


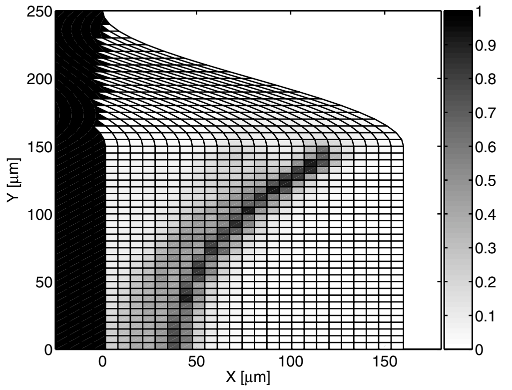

**Figure 1.** (a) Setup of disc flyer target, $r = 150\,\mu$m, $d = 11\,\mu$m, $L = 200\,\mu$m; (b) Density [g/cm$^3$] of 120 J /1.315 $\mu$m disc flyer at time 4.5 ns reaching the massive target, thick line at $x = 0$ is right boundary of the target, thick curve on right is zero contour of $x$-velocity component - all mass left of this curve is flying left.

**Table 1.** Parameters of disc flyer hitting massive target for different energies of the pulse and 1-st (upper half) and 3-rd (lower half) harmonics; $m_d$ is disc mass per 1 cm in $z$ direction (initial disc mass is $0.45 \cdot 10^{-4}$ g/cm), $T_d$, $v_d$ are mass averaged temperature and velocity of disc flyer from simulation and $v_e$ are disc velocities measured in experiment [5, 6] (? means that measurement data are not available).

| $E$[J] | $\lambda$[$\mu$m] | $m_d$ [$10^{-4}$ g/cm] | $T_d$ [eV] | $v_d$ [km/s] | $v_e$ [km/s] |
|---|---|---|---|---|---|
| 120 | 1.315 | 0.38 | 2.0 | 40 | 40 |
| 250 | 1.315 | 0.36 | 4.7 | 67 | 54 |
| 390 | 1.315 | 0.35 | 9.4 | 98 | ? |
| 120 | 0.438 | 0.37 | 4.8 | 68 | ? |
| 240 | 0.438 | 0.34 | 13.7 | 113 | ? |
| 390 | 0.438 | 0.33 | 34.5 | 159 | ? |

## 3. LASER INTERACTION WITH FLYER TARGET

The scheme of a disc flyer target problem is presented in Fig. 1(a). The intense laser irradiates thin Aluminum disc and the ablation pressure accelerates the disc against the thick massive solid Aluminum target. The energies 120, 250, 390 J of iodine laser pulse of 400 ps lenght with wavelengths $\lambda = 1.315\,\mu$m at 1-st and $\lambda = 0.438\,\mu$m at 3-rd harmonics are used. The problem parameters are similar to the experiments performed at the PALS laser facility [5, 6] in Prague. The simulation is split into two parts. In the first one the disc is irradiated by laser and ablatively accelerated towards massive target. The result of this part for 120 J pulse on first harmonics is shown in Fig. 1(b) (compare with interferograms in [5, 6]) shortly before hitting the massive target by higher density area. These data interpolated to the new special mesh as shown in Fig. 2(a) serve as initial conditions for the second part of the simulation – the impact of the flyer disc into the massive target. The averaged parameters of disc flyer for all types of laser pulse are summarized in Tab. 1. The disc flyer in plasma state hits the massive Aluminum target, raises its temperature and sinks into the target. A shock wave propagates into the target and a part of the disc and target material is reflected in low density corona-like shape. Most of the disc flyer energy is converted into the heat melting and evaporating a part of the target creating a crater as presented in Fig. 2(b) showing the temperature distinguishing three phases of Aluminum. The simulated craters sizes and shapes correspond reasonably well to the experimental measurements. Note that standard Lagrangian codes like ATLANT-HE are unable to simulate the flyer impact into the massive target due to mesh distortion.



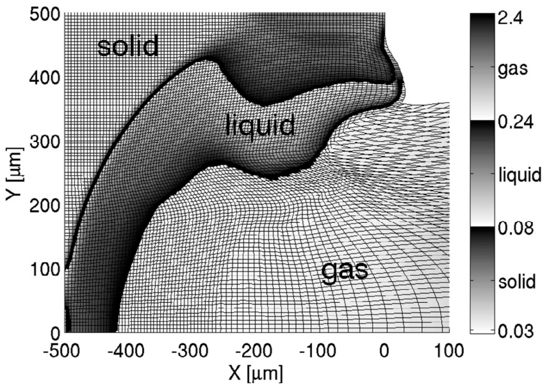




**Figure 2.** (a) Initial conditions for density [g/cm$^3$] obtained by interpolation of density data from Fig. 1(b) on the new mesh used for 120 J / 1.315 $\mu$m disc flyer impact simulation. (b) Temperature [eV] for 120 J/1.315 $\mu$ m disc flyer impact simulation at time 40 ns after disc impact.

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